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Optimization of Process Parameters of CNC Milling

Malay, Kishan Gupta, JaideepGangwar , Hasrat Nawaz Khan, Nitya Prakash Sharma, Adhirath Mandal, Sudhir Kumar, RohitGarg
Department of Mechanical Engineering, Greater Noida Institute of Technology, UP, India

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Abstract

CNC Vertical Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. During the face milling process, the material is removed by the 10 mm Dia tool. The effects of various parameters of milling process like spindle speed, depth of cut, feed rate have been investigated to reveal their Impact on surface finish using Taguchi Methodology. Experimental plan is performed by a Standard Orthogonal Array. The results of analysis of variance (ANOVA) indicate that the feed Rate is most influencing factor for modeling surface finish. The graph of S-N Ratio indicates the optimal setting of the machining parameter which gives the optimum value of surface finish. The optimal set of process parameters has also been predicted to maximize the surface finish.

1. Introduction

In present time the technology of CNC vertical milling machine has been improved significantly to meet the advance requirements in various manufacturing fields, especially in the precision metal cutting industry. This experiment gives the effect of different machining parameters (spindle speed, feed, and depth of cut) on surface finish in face milling. The demand for high quality and fully automated production focus attention on the surface condition of the product, surface finish of the machined surface is most important due to its effect on product appearance, function, and reliability. For these reasons it is important to maintain consistent tolerances and surface finish. Among several CNC industrial machining processes, milling is a fundamental machining operation.Face milling is the most common metal removal operation encountered. It is widely used in a variety of manufacturing in industries. During Face milling, the depth of cut is small. Technological parameter range plays a very important role on surface roughness. In Face milling, use of high cutting speed, low feed rate and low depth of cut are recommended to obtained better surface finish for the specific test range in a specified material. This experimental investigation outlines the Taguchi optimization methodology. The experiment is conducted on aluminium alloy (Al 6351) the processing of the job is done by High Speed Steel (HSS) tool under finishing conditions. The machining parameters evaluated are spindle speed, feed rate and depth of cut. The experiments are conducted by using Taguchi L9 orthogonal array as suggested by Taguchi. Signal to Noise (S/N) ratio and Analysis of Variance (ANOVA) is employed to analyze the effect of milling parameters on surface roughness.

Corresponding Author,
***E-mail address:** adhirath.mandal@gmail.com

2. Literature Review

V.S. Suresh and P. Venkateswara Rao [1] (2002) Adopted a two stage approach towards optimization of surface roughness. First, experimental results were used to build mathematical models for surface roughness by RSM. Then, the second order mathematical model was taken as an objective function and was optimized using genetic algorithm (GA) to obtain the machining conditions for a desired surface finish.

R. Noorani and Y. Farooque[2] (2008) The objective of this research was to study the effects of CNC machining processes on Aluminum alloy 6061 samples for its surface roughness. The main conclusion of this reason is that two factors highly responsible for the surface roughness are feed rate and tool size.

T. K. Barman et al.[3] (2009) have conducted experiments based on Taguchi L27 orthogonal array to investigate the effect of process parameters such as Cutting speed, Feed and Depth of cut on surface roughness in CNC milling. They selected AISI 1040 steels as work material. An optimum cutting parameter combination was found out for maximum fractal dimension and it may be useful in computer aided process planning.

S. Moshat and SauravDatta[4] (2010) In this experiment use of PCA based hybrid Taguchi method has been proposed and adopted for solution of multi-objective optimization, along with a case study, in CNC end milling operation. From the study and analyses, we conclude that this proposed method has been found efficient for solving multi-attribute decision making problem i.e., for multi-objective product as well as process optimization; for continuous quality improvement.

SurasitRawangwong et al.[5] (2012) had tried to investigate the effect of process parameters on the surface roughness in Al 7075-T6 face milling. The optimal setting for the selected process parameters was speed at 2930 rpm and the feed rates at 808 mm/min. They also had given mathematical model for surface roughness in term of selected process parameters.

M. D. Selvan and Dr. G. Karuppusami[6] (2012) performed on Mild Steel and obtained data has been analyzed using Taguchi technique and Genetic algorithm. It has been observed that, Taguchi's orthogonal array provides a large amount of information in a small amount of experimentation. The surface roughness evaluated through Taguchi technique is 0.975 µm with 4.308 % error from the predicted value and for genetic algorithm it is 0.88 µm with 4.625 % error from the predicted value.

Amit Joshi and Pradeep[7] (2012) had taken process parameters like spindle speed, depth of cut, feed rate to investigate to reveal their Impact on surface finish. They found the optimal setting for selected process parameters and optimal value of surface finish was obtained at first level of factor A, third level of factor B and second level of factor C. From the ANOVA analysis they were found that feed rate is the most dominating factor for surface finish.

Bharat Patel [8], 2012. The main objective of the experiment is to optimize the milling parameters (spindle speed, feed rate, depth of cut and cutting tool grade) to achieve low value of the surface roughness. The optimal condition for surface roughness in milling Aluminum was resulted at level 3 for spindle speed and it was 1200 rpm, at level 3 for feed rate and it was 500 rpm, at level 2 for depth of cut and it was 0.5 mm. The corresponding surface roughness is 1.034 µm.

Avinash A. Thakre[9] (2013) had applied Taguchi methodology for optimize the process parameters for surface roughness in CNC milling machine. The optimal parameters for surface roughness was obtained as spindle speed of 2500 rpm, feed rate of 800 mm/min, 0.8 mm depth of cut, 30 lit/min coolant flow.

Parveen Kumar and Deepak Chaudhary[10] (2013) According to this work mainly three cutting parameters named Spindle speed, Depth of Cut , Feed rate may be selected and optimize the Material Removal rate. The optimum value of MRR is 87.54 mm3/sec. obtained at Spindle speed 3500 r.p.m. & 0.6 mm of feed rate. So as we increase the Spindle speed & Depth of cut the MRR also increase.

3. Methodology

3.1 Taguchi Method

Taguchi Method is developed by Dr. Genichi Taguchi, a Japanese quality management consultant. The method explores the concept of quadratic quality loss function and uses a statistical measure of performance called Signal-toNoise (S/N) ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized. The standard S/N ratios generally used are as follows: - Nominal is Best (NB), Lower the Better (LB) and Higher the Better (HB).

In this project the experiments are designed with the help of taguchi L9 orthogonal array. The software used for DOE (Design of experiment) is Minitab17. The project contains many processes which are described one by one in the methodology respectively.

3.2 Input parameters and their levels

Table 1: Selected input Parameters

Controlfactors (unit)	Level 1	Level 2	Level 3
Spindle Speed (rpm)	800	1000	1200
Feed Rate (mm/min)	60	80	100
Depth of Cut (mm)	0.2	0.3	0.4

3.3Workpiece

The material used for the experiment is an aluminium alloy (Al 6351) of dimension 110 x 34 x 20 mm3. In this project we are using 9 blocks of aluminium alloy according to taguchi design. The workpiece material compositions are as follows.

Table 2: Material Composition

Mater ial	Si	Fe	C u	M n	M g	Zn	Ti	Al
Al 6351	0.9 3	0.3 6	0. 1	0.5 7	0.5 5	0.1 34	0.0 14	97.3 42

3.4 Design of experiments (DOE)

For selected input parameters experiments are designed using Taguchi L9 orthogonal standard array. For this purpose software Minitab 17 is used.

Table 3: Design of Experiment

Experiment No.	Spindle Speed	Feed Rate	Depth of Cut
1	800	60	0.2
2	800	80	0.3
3	800	100	0.4
4	1000	60	0.3
5	1000	80	0.4
6	1000	100	0.2
7	1200	60	0.2
8	1200	80	0.4
9	1200	100	0.3

3.5 Experimentation

After design of experiment, 9 experiments are carried out in CNC vertical Face milling. After each experiment surface roughness is calculated. A quality characteristic for surface roughness is "smaller is the better".

3.6 Instruments used for measuring surface roughness

Instrument used in this paper for measurement of surface Roughness is Mitutoyo Surftest SJ-201P. The surf test SJ-201P (Mitutoyo) is a shop–floor type surface-roughness measuring instrument, which traces the surface various machine parts and calculates the surface roughness based on roughness standards, and displays the results The surface roughness values as measured by the tester are given below-

Fig .1 Experiments on Vertical CNC Machine

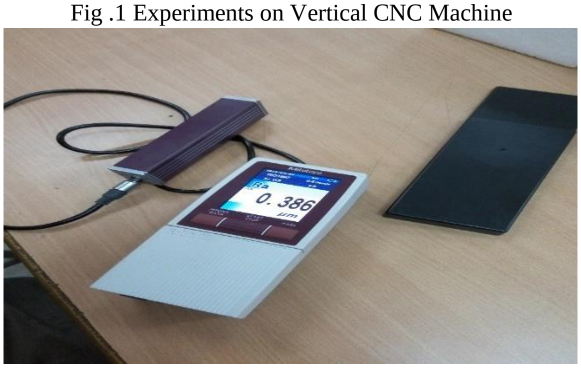

Fig.2 Mitutoyo Surftest SJ-201P Instrument

Table 4: Surface Roughness

Experiment no.	Spindle Speed	Feed Rate	Depth of cut	Surface Roughness
1.	800	60	0.2	0.300
2.	800	80	0.3	0.305
3.	800	100	0.4	0.314
4.	1000	60	0.3	0.294
5.	1000	80	0.4	0.291
6.	1000	100	0.2	0.298
7.	1200	60	0.2	0.280
8.	1200	80	0.4	0.282
9.	1200	100	0.3	0.311

3.7 Analysis of variance (ANOVA)

The output characteristic, surface finish is analysed by software Minitab 17 and ANOVA is formed, which shows the percentage contribution of each influencing factor on surface roughness. This also signifies that which factor is more dominant in CNC FACE MILLING.

From SN ratios curve this table is formed and the optimal set of parameter from is A3B1C1 (smaller is better).

Tables for Signal to Noise Ratios

This graph shows the objective of using the SN ratio as a performance measurement is to develop product and processes in sensitive to noise factor. From the graph we can see that the effect on surface roughness by increasing the value of each parameter. As per the graph higher value of spindle speed and lower value of feed rate and depth of cut will provide most optimum surface roughness. According to this graph this optimal set of parameters is A3B1C1.

Table 5: Response Table for Signal to Noise Ratios

Level	Spindle Speed	Feed Rate	Depth of Cut
1.	20.30	13.74	15.42
2.	15.83	15.24	17.10
3.	13.17	20.33	16.79
Delta	7.13	6.59	1.68
Rank	1	2	3

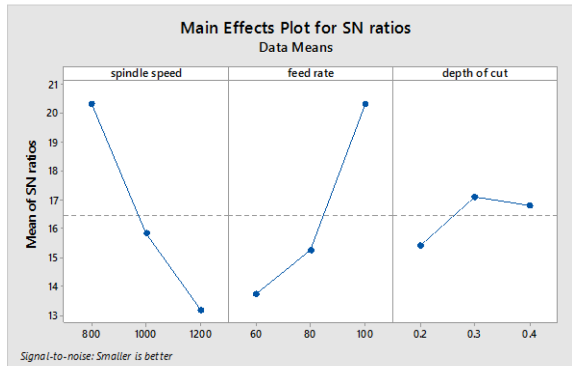

Fig. 3 SN Ratio Data and Input Parameter

Response Table for Means:

Table 6: Response table for Means

Level	Spindle Speed	Feed Rate	Depth of Cut
1.	0.1097	0.2243	0.1720
2.	0.1623	0.1767	0.1400
3.	0.2380	0.1090	0.1980
Delta	0.1283	0.1153	0.0580
Rank	1	2	3

The optimal combination of input machining parameter can be observed from fig 4 i.e. graph between S-N ratio and input parameter, the optimal setting of input parameter is (A3B1C1). The process parameter setting with the highest SN ratio always yields the optimum quality with minimum variation.

This interaction plot shows the dependency of one factor on the levels of other factors. In an interaction plot the parallel lines indicate the no interaction and the greater the difference in slope between the lines, the higher the degree of interaction. The interaction plot given by ANOVA. With the help of Minitab 17 the analysis of variance (ANOVA) is given as follows:

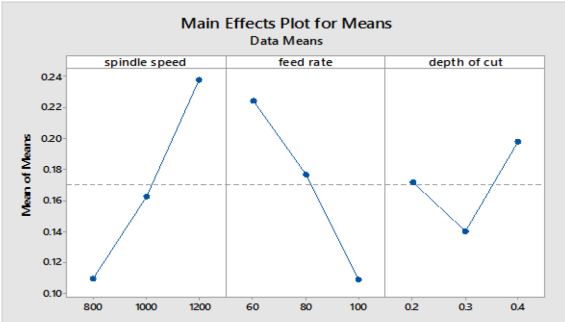

Fig. 4 Mean and Control Factors

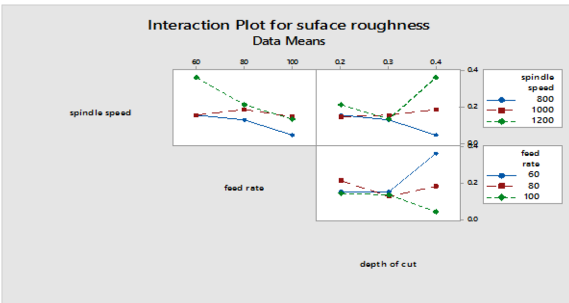

Fig. 5 Interaction Plot of All Factors for Surface Roughness

Table 7: ANOVA Result

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value
Regression	3	0.045671	0.015224	5.57	0.047
Spindle Speed	1	0.024704	0.024704	9.03	0.030
Feed Rate	1	0.019953	0.019953	7.30	0.043
Depth of cut	1	0.001014	0.001014	0.37	0.569
Error	5	0.013675	0.002735	-	-
Total	8	0.059346	-	-	-

From above table it can be seen that all the three factors are significantly affect the response (Surface Roughness). Spindle Speed has highest effect on the response, Feed rate has second highest effect on response and depth of cut has least effect on surface roughness.

4. Calculation And Results

4.1 Calculation for average performance of every factor: Average performance of each factor on surface roughness is calculated by following expression

Average performance of factor A at level 1= (Sum of all surface roughness's for factor A) / (no. of levels)

Similar expression can be written for calculating the average performance of factor B & C where A represents spindle speed , B represents feed rate and C represents the depth of cut. Now a/c to this formula-

Average performance of spindle speed at all levels respectively

(A1) = 0.298

(A2) = 0.294

(A3) = 0.291

Average performance of feed rate at all levels respectively

(B1) = 0.283

(B2) = 0.292

(B3) = 0.307

Average performance of depth of cut at all levels respectively

(C1) = 0.275

(C2) = 0.303

(C3) = 0.295

4.2 Calculation of Optimum Surface Finish :

Let T = average result for 9 runs of surface finish

T = (sum of all surface roughness's from table 4) / 9

= 2.534 / 9

= 0.281

Optimal surface roughness = T + (A3 – T) + (B1 – T) + (C1 – T)

Sopt = 0.281 + (0.298 - 0.281) + (0.283 - 0.28) + (0.275 - 0.28)

Sopt = 0.294

5. Results

*After completing the project it can be observed that optimal value of surface finish is obtained at third level of Spindle Speed, first level of Feed Rate and First level of Depth of Cut.

* Optimal value of surface finish is 0.294 µm.

* From the ANOVA it can be seen that the p-value of Spindle Speed is minimum that means Spindle Speed is the most dominating factor for modeling surface finish.

* The value of surface roughness evaluated through Taguchi technique is 0.294 µm with 4.987 % error from the predicted value.

6. Conclusions

- The influence of depth of cut, spindle speed and feed rate on machined surface roughness and material removal rate in face milling operation have been studied. The experiment has been performed on Al 6351 and obtained data has been analyzed using Taguchi technique. It has been observed that, Taguchi's orthogonal array L9 provides a large amount of information in a small amount of experimentation. All the three parameters are predominantly contributing to the responses and all have been considered. Optimum machining parameter combination has been found through Taguchi technique
- The main objective of the experiment is to optimize the milling parameters (spindle speed, feed rate and depth of cut) to achieve low value of the surface roughness. The experimental data for the surface roughness values and the calculated signal to noise ratio is shown in table.
- Taguchi's robust design method is suitable to optimize the surface roughness in milling Aluminum. The optimal condition for surface roughness in milling

Aluminum alloy 6351 was resulted at level 3 for spindle speed and it was 1200 rpm, at level 1 for feed rate and it was 60 mm/min, at level 1 for depth of cut and it was 0.2 mm. The surface roughness evaluated through Taguchi technique is 0.294 µm with 4.987 % error from the predicted value.

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